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CORRELATION OF FLAMEOUT AND IGNITION CHARACTERISTICS FOR DIFFUSION COMBUSTION OF FUEL BEHIND SYSTEMS OF ANGLE-BAR FLAMEHOLDERS

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CORRELATION OF FLAMEOUT AND IGNITION CHARACTERISTICS FOR DIFFUSION COMBUSTION OF FUEL BEHIND SYSTEMS OF ANGLE-BAR FLAMEHOLDERS

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ABSTRACT. Empirical parameters are proposed which correlate the flameout and ignition characteristics for flameholders of different width, opening angle, shape, and degree of shadowing of the burner by the flameholders.

A large number of studies have been published on the flameout characteristics of systems of trough-like flameholders when burning premixed fuel-air compositions behind the holders (in afterburners and the combustion chambers of ramjet engines). The use of such burners to provide effective combustion of fuel at high flow velocities with low pressure losses in the main combustion chambers and particularly in the gas interheater combustion chambers in gas turbine powerplants is very promising. However, the considerably higher overall excess air coefficients in such chambers require the use of the diffusion technique for supplying the fuel behind the flameholder. The working process in such combustion chambers has received very little study to date. /78*

The present authors have investigated at Kiev Polytechnic Institute and the Kaluga Turbine Plant the working process of an annular combustion chamber

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*Numbers in the margin indicate pagination in the original foreign text.

which is integrated into the turbine case of the interheater of a gas turbine powerplant operating on gaseous fuel [1, 2]. The high flow velocity level in the passages of such combustion chambers, resulting both from the higher volumetric gas flowrates and the small chamber cross section areas, imposes special requirements on the flameholding capability of the front assemblies. Therefore, the study of the flameout and ignition characteristics and development of methods for their correlation as a function of the geometric parameters of the head-end stabilizing devices take on particular urgency.

The flameout and ignition characteristics in the case of the diffusion technique for fuel supply into the circulation zone behind the flameholder are superficially similar to the flameout characteristics in the case of combustion of homogeneous fuel-air mixtures, although they are considerably broader with regard to excess air ratio. Moreover, on certain segments of the curves (the "rich" branch and the flat segment of the "lean" branch) the flameout mechanism for the diffusion fuel supply technique is different — fuel burnup takes place in the diffusion regime. The broader range of stable operation with regard to excess air ratio is explained by the fact that prior to "lean" flameout only the air introduced into the circulation zone by turbulent pulsations, or part of this air in the case of flame localization within the zone, takes part in the flame stabilization process. In both cases the flame stabilization processes are determined by the intensity of the processes of mass and heat transfer between the circulation zone and the outer flow, which depend on the flow velocity, size and shape of the flameholders, and other geometric and operating regime factors. Therefore, the nature of the curves is the same in both cases; with reduction of the flow velocity, the range of stable operation with regard to excess air ratio broadens.

The ignition characteristics are similar to the flameout curves; however, /79 they are associated with a narrower operating regime range, which is explained by the limited power of the electric igniter discharge (igniters of the SPE-04-A type were used). In connection with the similar nature of the

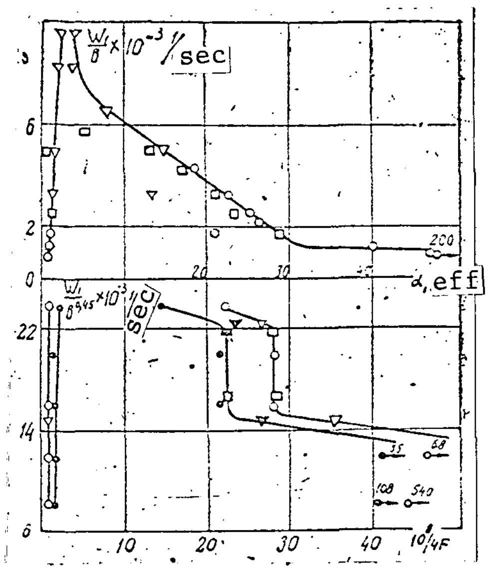

Figure 1. Universal flameout and ignition curves for flameholders of different width. Flameholders: opening angle β = 60°, front assembly blockage f = 32.5 - 36.7%, fuel supply uniform across face.

Flameholder width, mm	Curves	
	Flameout	Ignition
60	○	●
30	□	■
15	▽	▼

Regime: initial temperature t_1 = 600°C, excess air ratio in forechamber α_{fc} = = 4.5, pressure P_1 = 1 atm. Fuel is natural gas from the Shebelinskiy field.

phenomena, correlation of the experimental data on flameout and ignition for flameholders of different absolute width is accomplished using the same parameter (Figure 1)

$$\frac{W_1}{B} = f(\alpha_{1\,eff}) \tag{1}$$

where W_1 is the flow velocity at the flameholder at the moment of flameout and ignition, m/sec; B is the flameholder width, m; $\alpha_{1\,eff} = \alpha \frac{f}{1-f}$ is the effective (proportional to the actual) excess primary air ratio; α is the overall excess air ratio; $f = \frac{F_{fh}\Sigma}{F_{fh}\Sigma + F_{clear}\Sigma}$ is the front assembly blockage ratio; F_{fh} is the total area shadowed by the flameholders; F_{clear} is the total clear area.

When the fuel is fed into the counterflow zone prior to "lean" flameout, it is possible that the flame will be localized within the zone (plume dimensions are smaller than the counterflow zone) in connection with the existence in this zone of large fuel concentration nonuniformities, determined by the diffusion fuel supply technique, by the scheme (place) of fuel input into the zone, and the aerodynamic structure of the zone. Broadening of the range of stable operation with respect to α_{1eff} with reduction of the flow velocity is observed only down to some flow velocity, after which this range narrows and $\alpha_{1eff} \sim W_1$, i.e., along the line of minimal fuel flowrate ($G_{f\,min}$ = const). Apparently the limiting minimal flame plume size for each /80 fuel supply scheme for which the fuel concentration in the plume is sufficient for the combustion process to proceed and the heat balance required for flame stabilization is maintained depends on the flowrate $G_{f\,min}$.

Analysis of (1) does not give any idea of the location of the limiting segment. The transition region shows up most clearly when using the correlation parameter

$$\frac{W_1}{B^{0,45}}=f\left(\frac{\alpha_{1eff}}{W_1}\right)\sim\varphi\left(\frac{1}{U_F}\right), \tag{2}$$

where $U_F=\frac{G_t Q_p^{N}}{F_{fh}\Sigma P_1}$ is the heat release rate of the flameholder face; G_f is the fuel mass flowrate, kg/hr; P_1 is the stream pressure; Q_p^N is the lower heating value of the fuel, kcal/kg.

When using this approach, the transition segments for flameholders of different width superpose (Figure 1), i.e., the relative fuel flowrates for which flameout and ignition take place are the same on the transition segments for each fuel supply technique. For example, when supplying the fuel uniformly over the flameholder face the transition segment for the ignition curves corresponds to $10^8/U_F$ = 22 sec/m, and for the flameout curves it corresponds to $10^8/U_F$ = 28 sec/m. These results confirm the assumption of a minimal limiting flame plume volume, defined by $G_{f\ min}$. The transition segments for the two curves also occupy the same position along the ordinate axis $15\cdot 10^3 < W_1/B^{0,45} < 22\cdot 10^3$. This is indicative of proper choice of the correlation parameter, which reflects the variation of the intensity of the mass and heat transfer processes in the circulation zone as a function of the hydrodynamic parameters.

Increase of the flameholder opening angle leads to broadening of the stable operation range. Analysis of the curves for flameholders with different opening angles showed that the experimental points are correlated well by the parameter

$$\frac{W_1}{B\left(\frac{\sin\beta}{\sin\beta_0}\right)^{0,11}} = f(\alpha_{1\ eff}) \tag{3}$$

where β_0 and β are the flameholder opening angles for the known and unknown curves (Figure 2). The correlating correction $(\sin\beta/\sin\beta_0)^{0,11}$, which accounts for the relative deflection of the flow by the flameholder walls, is proportional to the square root of the ratio of the relative burner resistances $\Delta P_b/q$ for the flameholders being analyzed

$$\left(\frac{\sin\beta}{\sin\beta_0}\right)^{0,11} \sim \left(\frac{\Delta P_{b\beta}}{\Delta P_{b\beta_0}}\frac{q_0}{q}\right)^{0,5},$$

where ΔP_b is the burner resistance, $q = \rho W_0^2/2$ is the dynamic head forward of the flameholder grid.

For flameholders with varying width along their height, the combustion stability is determined by the maximal flameholder width B_{max}. Therefore, the experimental data are correlated satisfactorily by the parameter

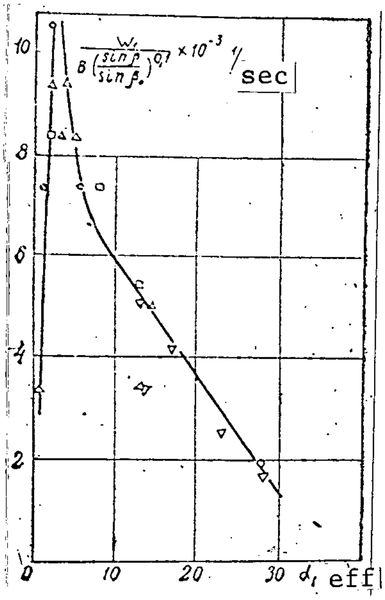

Figure 2. Universal flameout curve for flameholders with different opening angles. Flameholders: f = 32.5 - 36.7%, fuel supply uniform across face; β = 60°. Regime same as in Figure 1.

Flameholder width	Opening angle β, deg	Symbol
15	24	○
15	32	□
15	60	△
30	60	▽

$$\frac{W_1}{B_{max}} = f(\alpha_{1\,eff}) \qquad (4)$$

However, we note that partial separation of the flame behind the narrow part of the flameholder in the regimes prior to flameout delay the fuel burnup process significantly. Therefore, for burners with limited area of the front assembly, operating at a high flow velocity level, flameholders of constant width should be used. /81

The point of most stable ignition is the counterflow zone behind the widest part of the flameholder if it has variable width, and the region of the flame bars if the flameholder has constant width, i.e., those regions where the zone has the maximal size and provides the longest fuel "stay time" in the zone.

Improvement of flameholder "aerodynamic streamlining" narrows the stable operating range. In the versions in which the aft part is narrower than the midsection dimension of the flameholder, the stable operating range is determined by the dimensions of the aft part. Beveling or rounding of the flameholder edges leads to a similar effect.

Increase of front assembly blockage by the flameholders for a constant flow velocity in the clear spaces between the flameholders leads to broadening of the stable operating range, since the combined deformation of the flow by the flameholders and the flame bars, which interconnect the flameholders, increases the length and, therefore, the stabilizing capability of the circulation zone increases [2].

Analysis of the experimental data for units with the same flameholders (B = 21 mm, β = 38°), but different blockage (f = 36.7 - 60.3%), using the correlation parameter

$$\frac{W_1}{B\frac{1-f_0}{1-f}} = \varphi(\alpha_{1\,\mathrm{eff}}) \qquad (5)$$

shows that the stable operating range (with respect to the approaching flow velocity, W_0, and $\alpha_{1\,\mathrm{eff}}$) is independent of the blockage ratio f (Figure 3).

Since for two front assemblies with constant approaching flow velocity $W_0 = W_1(1-f) = W_{10}(1-f_0)$, the velocities at the flameholder are related by the expression $W_{10} = W_1\; 1-f/1-f_0$. Thus, the increase of the velocity W_1 with /82
increase of the ratio f is compensated by the increase of the stabilizing capability of the system of flameholders.

The proposed empirical parameters make it possible to correlate the flameout and ignition characteristics for front assemblies consisting of systems of radial flameholders over a wide range of variation of the geometric parameters. Experiments showed that the stable operating range for the system of flameholders is considerably broader (with regard to $\alpha_{1\,\mathrm{eff}}$ and W_1) than for

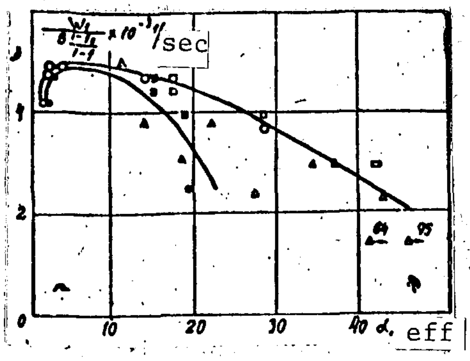

Figure 3. Universal flameout and ignition curves for front assemblies of different blockage ratio. Flameholders: B = 21 mm, β = 38°, fuel supply uniform across face; f_0 = 36.7%. Regime same as in Figure 1.

Blockage, %	Curve	
	Flameout	Ignition
36.7	○	●
47.7	□	■
60.3	△	▲

individual flameholders. The results of model tests can be used for the design of full-scale combustion chambers.

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